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PHYSICS.—*Some notes on the theory of the Rayleigh-Zeiss interferometer.* By LEASON H. ADAMS, Geophysical Laboratory. Communicated by ARTHUR L. DAY.

In the course of some work on the freezing point of dilute aqueous solutions in which a Zeiss interferometer was employed as a means of determining the concentration of the equilibrium solutions,[1] some trouble was experienced at first in obtaining thoroughly concordant readings; this was found to be due to an alteration of the achromatic reference fringe produced by differences in optical dispersion. In order to guard against error from this source it proved necessary to investigate the relationships in order to derive formulae from which the exact amount of shift of the achromatic fringe could be predicted. The appropriate formulae for this type of instrument have apparently not been worked out heretofore;[2] consequently it has seemed worth while to call attention to these relationships and to put the formulae on record so as to save trouble to future users of this most useful type of instrument.

1. *The optical path-differences resulting from the tilting of a plane-parallel glass plate.* In the form of interferometer under consideration the difference in optical path-length of the two interfering beams of light is compensated by tilting one of two

[1] L. H. Adams, J. Am. Chem. Soc., 37, 481 (1915). A paper dealing with the use of this form of interferometer in the analysis of solutions is in course of publication in the J. Am. Chem. Soc.

[2] Except, possibly, in part by Siertsema in 1890 in a Groningen dissertation, a copy of which I have been unable to secure.

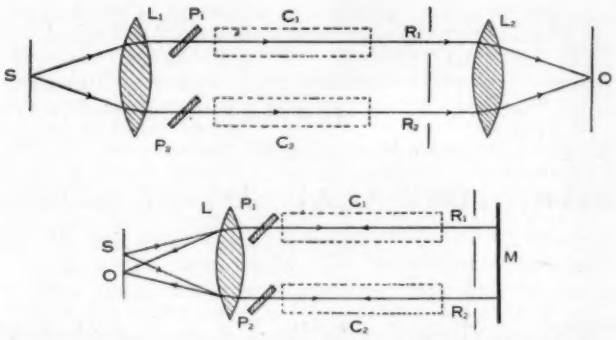

Fig. 1. Diagram of optical arrangement of interferometer; the two interfering beams are separated and reunited in (*a*) by two lenses, in (*b*) by a single lens.

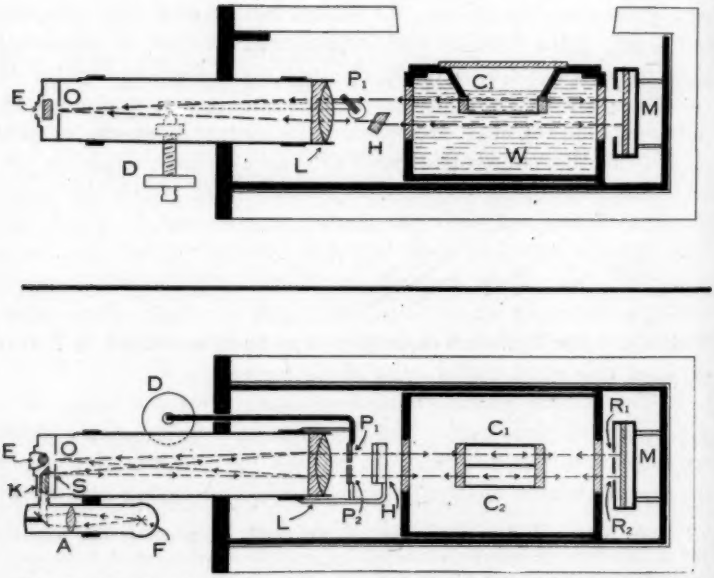

Fig. 2. Drawing in plan (below) and elevation (above) of the Zeiss Water Interferometer.

interposed glass plates (P_1, P_2, fig. 1); the amount of this tilting is then a measure of the path-difference between the two sides and hence of the difference in refractive index of the contents of the pair of cells C_1, C_2. The compensator plate is fastened at an angle of about 45° to a movable arm parallel to the direction of the light and is tilted by means of a micrometer screw which bears against the arm and moves in a fixed direction perpendicular to the arm when in its zero-position (see fig. 2). The optical path-difference resulting from the tilting of the plate through a certain angle θ may be calculated as follows:

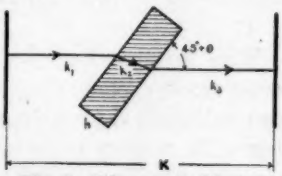

Fig. 3. Diagram to illustrate path of light beam through compensator plate.

Consider a certain path, of length K, traversed by a beam of light, and introduce into this path a plane-parallel glass plate (fig. 3). Let 45° + θ be the angle of incidence, h the thickness of the plate, n its refractive index and n_o that of the surrounding medium (air). It may easily be shown that the air-path of the beam

$$k_1 + k_3 = K - \frac{h}{\sqrt{2}}\left[\cos\theta + \sin\theta + \frac{n_o\,(1 - \sin 2\theta)}{\sqrt{2n^2 - n_o^2(1 - \sin 2\theta)}}\right]$$

and that the glass-path

$$k_2 = \frac{\sqrt{2}\,n\,h}{\sqrt{2\,n^2 - n_o^2\,(1 - \sin 2\theta)}}$$

Now the optical path-length P is by definition equal to $\Sigma\, k\, n$. Accordingly,

$$P = n_o K - \frac{h}{\sqrt{2}}\left[\sqrt{2\,n_2 - n_o^2\,(1 - \sin 2\theta} - n_o\,(\cos\theta + \sin\theta)\right]$$

Ordinarily $n_o - 1$ is very small compared to $n - 1$; consequently we may put $n_o = 1$. Then if we write $H = 2n^2 - 1$, we have

$$(1) \qquad P = K - \frac{h}{\sqrt{2}}\left[\sqrt{H + \sin 2\theta} - (\cos\theta + \sin\theta)\right]$$

In the initial position (angle of incidence = 45°) $\theta = 0°$, and therefore

$$P_o = K - \frac{h}{\sqrt{2}}\left(\sqrt{H} - 1\right) \tag{2}$$

Hence, the optical path difference p resulting from the tilting of the plate through an angle θ is

$$p = P_o - P = \frac{h}{\sqrt{2}}\left[\sqrt{H} - 1 - \sqrt{H + \sin 2\theta} + \cos\theta + \sin\theta\right] \tag{3}$$

This formula may be applied in a number of ways. For a compensator plate of given thickness and refractive index one can calculate the sensitiveness of the instrument by differentiating with respect to θ; moreover its range for given values of θ may be readily computed.

It is interesting to note the relation between sensitiveness and refractive index of the plate. For $\theta = 0°$

$$\frac{dp}{d\theta} = \frac{h}{\sqrt{2}}\left(1 - \frac{1}{\sqrt{H}}\right) \tag{3a}$$

The values of $dp/d\theta$ for plates of unit thickness are shown below.

refractive index n	*sensitiveness* $dp/d\theta$
1.5	0.34
2.0	0.44
2.5	0.51
3.0	0.54

Inspection of this table shows the comparatively small influence of refractive index on the sensitiveness of the compensator plate.

In a modified form it may also be used to obtain a small correction to the reading (on the drum D of the micrometer screw) such that the "corrected reading" will be strictly proportional to the refractive index difference (ν) of the solutions or mixtures under investigation. Thus if R is the travel in mm. of the screw and a the length in mm. of the arm—that is the constant perpendicular distance between the center of rotation and the line of motion of the screw—then $\theta = \tan^{-1}\frac{R}{a}$. Hence

eliminating θ from equation (3) we have

$$(4) \qquad p = \frac{h}{\sqrt{2}}\left(\sqrt{H} - 1 - \sqrt{H + \frac{2Ra}{R^2 + a^2}} + \frac{R + a}{\sqrt{R^2 + a^2}}\right)$$

which reduces with sufficient approximation to the power series

$$(5) \qquad p = \frac{h}{\sqrt{2}}\left[R\,\frac{1 - \frac{1}{\sqrt{H}}}{a} - R^2\,\frac{1 - \frac{1}{H^{1.5}}}{2a^2} + R^3\,\frac{\frac{1}{\sqrt{H}} - \frac{1}{2}}{a^3}\right].$$

Now let R'^{-1} be a quantity such that

$$\frac{R'}{a} = \frac{\sqrt{2}\,p}{h\left(1 - \frac{1}{\sqrt{H}}\right)}$$

then

$$(6) \qquad R' = R - R^2\,\frac{1 - \frac{1}{H^{1.5}}}{2a\left(1 - \frac{1}{\sqrt{H}}\right)} + R^3\,\frac{\frac{1}{\sqrt{H}} - \frac{1}{2}}{a^2\left(1 - \frac{1}{\sqrt{H}}\right)}$$

As an example, in our instrument (the Zeiss Water-Interferometer) $a = 110$ mm. and $n_D = 1.514$; moreover, if r represents the number of divisions on the drum corresponding to a given value of R, $r = 200\,R$ (also $r' = 200\,R'$); for these values formula (6) reduces to the expression

$$(6a) \qquad r' = r - 41.07\left(\frac{r}{1000}\right)^2 + 0.12\left(\frac{r}{1000}\right)^3$$

in which the last term is almost entirely negligible. Values of R' (and hence also of r') calculated in this way are proportional to the decrease in optical path resulting from the tilting of the compensator plate, and therefore strictly proportional to the quantity ν, the refractive index difference of the solutions.

Another use to which formula (3) may be put is the calculation of the variation with refractive index n of the path difference p corresponding to a given angle θ. Thus by differentiation,

$$\frac{dp}{dn} = \sqrt{2}\, h n \left(\frac{1}{\sqrt{H}} - \frac{1}{\sqrt{H + \sin 2\theta}} \right) \tag{7}$$

whence by combination with (3), we have

$$\frac{dp}{p} = 2 n\, dn \, \frac{\dfrac{1}{\sqrt{H}} - \dfrac{1}{\sqrt{H + \sin 2\theta}}}{\sqrt{H} - 1 - \sqrt{H + \sin 2\theta} + \sin\theta + \cos\theta} \tag{8}$$

For small values of θ (the usual case) we may write $\sin\theta = \theta$ and $\cos\theta = 1$. The above expression then reduces with sufficient approximation to the following:

$$\frac{\Delta p}{p} = \frac{2 n\, \Delta n}{H(\sqrt{H} - 1)} \tag{9}$$

For ordinary crown glass $n = 1.52$ and the above formula reduces to

$$\frac{\Delta p}{p} = 0.94\, \Delta n \tag{9a}$$

Now for the change of path p, caused by the insertion of successive plane-parallel plates perpendicular to the direction of the light, $p_1 = h(n - 1)$ and therefore $dp_1/p = dn(n - 1)$. But $dn/(n - 1)$ is the ordinary "relative dispersion." Hence if we write (9) in the form

$$\frac{\Delta p}{p} = q \frac{\Delta n}{n - 1} \tag{10A}$$

where

$$q = \frac{2 n (n - 1)}{H(\sqrt{H} - 1)} \tag{10B}$$

q is then the factor by which we must multiply the relative dispersion of the glass plate in order to obtain the proportional change of path $(\Delta p/p)$ resulting from a given increase (Δn) of the refractive index of the plate. The value of q for ordinary

crown glass ($n = 1.52$) is 0.48. We shall have occasion to use formula (10) when we come to the subject of the alteration of the achromatic fringe in white light.

As a check on the above relations some observations with monochromatic light (obtained by means of a Monochromatic Illuminator) of several wave lengths were made on the relation between the number of divisions on the drum and the number of fringes crossing the field. For wave lengths 0.5876 and 0.5461 He and Hg tubes respectively were used, and an arc lamp for wave-lengths 0.6396 and 0.4861, the slits of the Illuminator in the latter case being very narrow, in order to obtain sufficiently homogeneous light. The character of the results is shown by Table I for wave-length 0.5876 −.

TABLE I

N	r	r'	r'/N	δr OBS.-CALC.
5	112	111.5	22.25	−1.0
10	227	225	22.50	+0.5
20	459	450.5	22.52	+1.5
30	695	675	22.50	+1.7
40	934	898	22.45	+0.1
60	1429	1345	22.42	−1.7
80	1950	1795	22.44	−0.6
100	2499	2244.5	22.445	−0.2
120	3080	2693.5	22.445	−0.3

Average = 0.8

The first and second columns give respectively the number of fringes N and the corresponding observed number of scale divisions r. The third column gives the values of r' calculated by equation (6 a) and the fourth, the quotient r'/N which inspection shows to be practically constant, as it should be. The least square mean value of this quotient is 22.447; the differences between this mean and the individual observations, when computed back in terms of r, are given in the last column, which shows that this discrepancy is no larger than the error of reading (1 division, which is less than 1/20 of a band).

The values of r'/N for the other wave-lengths, determined similarly are shown in the second column of the table 2.

TABLE II

λ	r'/N	r'	N_x	$N_x\lambda$ ($= p_x$)	$\frac{\Delta p}{p_x}$	Δn	Δn (DIRECT DETN.)
0.6396	24.456	(2634)	107.70	68.88	0.0068	0.0072	0.0074
0.5876	22.447	(2634)	117.34	68.94	0.0058	0.0062	0.0056
0.5461	20.812	(2634)	126.56	69.11	0.0035	0.0037	0.0036
0.4861	18.462	(2634)	142.67	69.36	(0.0)	(0.0)	(0.0)

These values of r'/N were used to caluclate the values of N_x in the fourth column, N_x being the wave-lengths for various numbers of fringes corresponding to $r = 3000$ (and hence to $r' = 2634$). The next column contains the values of $N_x\lambda$, which is equal to p_x, the path difference (for 3000 divisions) for the given wave-length, while the sixth and seventh columns contain respectively the proportional variation of p_x (that is, $\Delta p/p_x$), and the change (n) of refractive index of the compensator plate calculated from $\Delta p/p_x$ by means of formula (9 a). The values of Δn calculated in this way agree satisfactorily with the direct measurements (shown in the last column) of the refractive index of the plate for the various wave-lengths.

2. *The shift of the achromatic fringe in white light.* This shifting of the achromatic fringe relative to the original central reference fringe is common to all compensation interferometers when used with white light. We may best understand what happens by supposing that the concentration of a solution in C (figs. 1 and 2) is increased slowly and continuously from zero onwards and that at the same time the original achromatic band is kept central by appropriate movement of the compensator. We would then in most cases observe, that the original achromatic band gradually becomes colored at the edges, while the adjacent bands to right and left become respectively more and less strongly colored; with further increase of concentration the central band becomes identical in appearance with the band on the left, and at length the latter is achromatic while

the central band is now particolored like the right hand band was originally. The comparison band has thus *apparently* shifted one band to the left; with further increase of concentration the same sequence of events occurs, and the apparently correct comparison band is shifted one additional band to the left for a certain concentration difference, this difference being (on our instrument) about 0.07 per cent (300 divisions) for KCl while for KNO_3 this concentration interval is considerably less. Now, since in making readings on a series of solutions of a substance we must obviously always make the final setting upon the same band, we shall err if the setting is made each time upon the most nearly achromatic band; and there will be one discontinuity for each such "concentration interval." The explanation of this shift of the achromatic band is found in the relative optical dispersion of solution and water, on the one hand, and of glass (of the compensator plates P_1, P_2) and air, on the other hand; for it is to be noted that in the type of instrument under consideration the lengthening of the optical path due to replacement of water by solution is compensated by the shortening of the *same* path by decreasing the effective thickness of an interposed glass plate. We shall now proceed to develop a formula by the aid of which errors arising from this source can be readily obviated.

This equation may be derived by making use of the principle that in general the position of the achromatic fringe is determined not by the condition (as in the case of the central fringe in monochromatic light) that the geometrical path difference shall be equal to the optical path difference, but by the condition that at the center of the achromatic fringe the change of phase with respect to wave-length shall be a minimum.[3] Accordingly if the combined effect of a decrease p in optical path-length due to the movement of the compensator and of an increase in path-length due to the replacement of a thickness l of water by solution is to displace the central bright band to a point O', this displacement N_λ, in terms of fringes for the wave-length λ, is given by

[3] See R. W. Wood, Physical Optics, 2nd Ed., 1911, p. 140.

$$N_\lambda = \frac{D}{\lambda}$$

D being the geometrical (and also the optical) path difference at O'. The achromatic fringe will similarly be displaced N'_λ fringes (again of wave-length λ) to a point (say Q), where

$$N'_\lambda = \frac{D'}{\lambda}$$

Now if the refractive indices of solution, water, and glass are represented by n_1, n_2 and n respectively and if we put $\nu = n_1 - n_2$ (with appropriate subscripts attached to ν and n to denote the wave-lengths to which they refer), then

$$D = \nu l - p$$

Consequently since ν, n, and hence p are all functions of λ we may write

$$D = f(\lambda)$$

We next determine D' in terms of $f(\lambda)$. Now the phase difference ϕ at Q is

$$\phi = 2\pi(D' - D)/\lambda;$$

Applying the necessary condition, $d\phi/d\lambda = 0$, we find

$$D' = f(\lambda) - \lambda f'(\lambda)$$

where $f'(\lambda) = df(\lambda)/d\lambda$. Accordingly

$$N_\lambda - N_\lambda = \frac{D'}{\lambda} - \frac{D}{\lambda} = -f'(\lambda)$$

To evaluate $f'(\lambda)$ we write for the variation of refractive index with wave length, according to the simple dispersion formula

$$n = A + \frac{B}{\lambda^2}$$

also

$$n_1 = A_1 + \frac{B_1}{\lambda^2}$$

and

$$n_2 = A_2 + \frac{B_2}{\lambda^2}$$

Therefore

$$N'_\lambda - N_\lambda = -f'(\lambda) = \frac{2}{\lambda^3}(B_1 - B_2)\, l - \frac{dp}{d\lambda}$$

Eliminating dp by formula (10) we obtain finally

$$N'_\lambda - N_\lambda = \frac{2}{\lambda^3}\left[(B_1 - B_2)\, l - qp\frac{B}{n-1}\right] \tag{11}$$

This expression gives the position of the achromatic fringe relative to the central fringe for any wave-length λ. Now if by the combined effect of the change in concentration of the solution and of movement of the compensator the position of the fringes for wave-length λ remains unchanged—that is, if, as in actual practice, the solution has shifted these fringes N_i fringes to the left and the compensator an equal number to the right—then $N_\lambda = 0$; moreover

$$N_i = \frac{\nu\, l}{\lambda} \text{ and obviously must also } = \frac{p}{\lambda}$$

Combining these relations with (11) we have

$$\frac{N'_\lambda}{N_i} = \frac{2}{\lambda^2}\left(\frac{B_1 - B_2}{\nu} - q\,\frac{B}{n-1}\right) \tag{12}$$

It will be convenient to take for λ that wave-length which corresponds to maximum luminosity in the spectrum of the light source (a tungsten lamp); this was found to be $\lambda = 0.58$. Now since $n_r - n_C = B\,[1/(.486)^2 - 1/(.656)^2] = 1.91\,B$, it follows that

$$\frac{B}{n_D - 1} = \frac{\beta''}{1.91}$$

where β'' is the ordinary relative dispersion of the glass plate, and similarly if we define the dispersive power[4] (β')

[4] It is to be noted that β' is not the same as the difference in relative dispersion of the solution and water; i.e.,

$$\frac{n_{1F} - n_{1C}}{n_{1D} - 1} - \frac{n_{2F} - n_{2C}}{n_{2D} - 1}$$

is not equal to $(\nu_F - \nu_C)/\nu_D$. Values of β' and β'' can be found, or calculated from data, in tables of constants.

of the solution with respect to water by the relation

$$\beta' = \frac{\nu_F - \nu_C}{\nu_D}$$

then $(B_1 - B_2)/\nu = \beta'/1.91$. Finally therefore

$$\frac{N'_\lambda}{N_t} = \frac{2(\beta' - q\beta'')}{(.58)^2 \times 1.91} = \frac{\beta' - q\beta''}{0.320} \tag{13}$$

This expression gives the numbers of fringes N'_λ through which the comparison band apparently shifts, in relation to the total number of fringes N_t corresponding to the position of the compensator; in actual practice it is more convenient to put $N_t = r/r_f$ where r_f denotes the number of divisions on the drum corresponding to one fringe in white light. Making this substitution, and putting $N'_\lambda = 1$, we find the corresponding reading r_1 to be

$$r_1 = 0.320\ r_f/(\beta' - q\beta'') \tag{13 a}$$

in other words, for each interval of $0.320\ r_f/(\beta' - q\beta'')$ divisions the achromatic fringe will have shifted one fringe to the left of the original bright band. Consequently for any solution or mixture for which β' is known, the amount of shift can be accurately calculated in advance;[5] the shift can therefore be allowed for, and any error from this source obviated.

In conclusion it may be remarked that in two of the three forms of Zeiss instrument—viz., in the portable gas interferometer and the water interferometer—the light passes twice through the compensator plate and hence the right hand member of equations 1 to 7 inclusive must be multiplied by 2 when applied to these instruments. Only slight modification of the formulae is required to enable them to be applied to any form of compensation interferometer.

[5] Examples of the application of this formula may be found in the paper already referred to, now in course of publication.

PHYSICAL CHEMISTRY.—*A vacuum furnace for the measurement of small dissociation pressures.* R. B. SOSMAN and J. C. HOSTETTER, Geophysical Laboratory.

The study of those silicate systems which contain iron requires the measurement of a wide range of oxygen pressures. The first problem in this connection is the study of the dissociation pressures of the oxides of iron themselves. For this purpose the apparatus described below has been developed.

Vacuum furnaces in considerable variety have already been described, but none of these was exactly suited to the work in hand. Furnaces like those of Arsem, Ruff, and numerous others, in which the heating element is of graphite or carbon, are of course out of the question when iron and oxygen are to be studied. Tungsten and molybdenum furnaces, like that of Birnbräuer, cannot be used with oxygen. Slade's platinum tube furnace is designed for a horizontal heating tube, which is not suitable for the quenching of silicate melts by dropping them into mercury. Another disadvantage of Slade's furnace is the softness of platinum at high temperatures, permitting the heating tube to be easily deformed.

Our furnace and accessory apparatus are shown in somewhat diagrammatical section in figure 1. The design could no doubt be improved, as some parts are the product of evolution rather than of original design, but the description covers the apparatus as it is actually being used for the measurement of small dissociation pressures. In principle, the furnace is similar to that of Slade.[1] It consists essentially of two parts: (1) the furnace tube, which serves both as the furnace wall inclosing the "inside vacuum" and as the heating element; (2) the water-cooled jacket, which surrounds the furnace tube and incloses the "outside vacuum."

An alternating current at low voltage is sent through the furnace tube, which is made of an alloy of 80 parts platinum and

[1] R. E. Slade, An electric furnace for experiments in vacuo at temperatures up to 1500°. Pr. Roy. Soc. London. **87** *A*: 519–524. 1912.

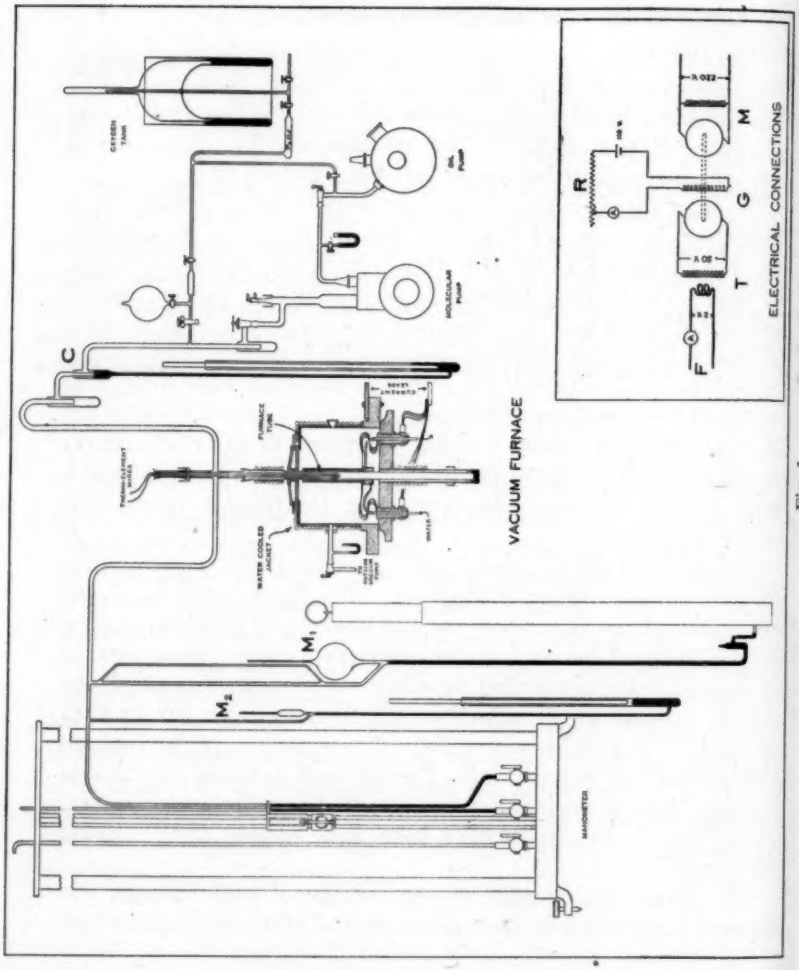
VACUUM FURNACE
ELECTRICAL CONNECTIONS
R
G
M
T
F
C
M_1
M_2
MANOMETER
WATER COOLED JACKET
FURNACE TUBE

Fig. 1

20 rhodium.[2] The tube is 15 mm. inside diameter and 200 mm. long, with walls 1 mm. thick. The current is carried in by water cooled terminals; the upper terminal is fixed to the furnace jacket, while the lower terminal moves with the expansion and contraction of the furnace tube. The cooling water is led into the lower terminal by lead pipes, and the current is carried by a sheaf of flexible copper strips. The lower leads are insulated from the furnace jacket by the stone base of the jacket, and are prevented from accidentally touching the walls by mica sheets around the inside of the jacket.

The platinum-rhodium alloy has the great advantage over pure platinum of great mechanical strength and stiffness. Platinum-iridium alloys are even stronger mechanically, but the volatility of the iridium forbids its use where thermoelements are to be used. The stiffness of platinrhodium is shown by our experience with the nitrogen thermometer, which had a 200 cc. bulb made of the alloy containing 20 per cent rhodium. At 1100°, one atmosphere outside with about 200 mm. pressure inside produced no observable change in the volume of the bulb after cooling, although a difference of 0.05 cc. or 1 part in 4000 could have been easily detected. The strength of the platinrhodium tube was put to the test when during some measurements at 1300° a glass connection was broken, allowing air at atmospheric pressure to rush into the inside of the furnace tube while the outside was still evacuated; we could detect no bulging of the furnace tube resulting from the accident.

The lower end of the platinrhodium tube is extended by a steel tube, capped with a screw cap and sealed with kollolith.[3] The upper end is likewise extended by a steel tube into which a glass tube is sealed, by the method of Kraus. This is an extremely useful type of joint, now being used in the manufacture of X-ray tubes, and should come into much wider use in vacuum apparatus.

[2] The tube was made by Dr. Heraeus of Hanau, to whom we have several times had occasion to express our indebtedness for his interest in the forwarding of high temperature investigations.

[3] A Canada balsam substitute of constant melting point and low vapor pressure, made by Voigt & Hochgesang.

Branches from the glass tube connect with the Gaede molecular vacuum pump on the one hand and with the pressure gages on the other. These connections are made with wide bends to take up stresses due to movements of the furnace and gages with changing temperature. All the glass tube connections are large, to facilitate rapid pumping to low pressures. The molecular pump delivers into a Gaede oil box pump, with which it is connected by a wide glass tube. The glass connection from the furnace to the molecular pump is provided with a removable conical ground cap (as shown in fig. 1), so that the pump can be washed without interference with the rest of the apparatus. A stopcock is also attached here, so that the pump can be used for other work. A $CaCl_2$ drying tube connected between the molecular and box pumps allows the pumps to be filled with dry air before stopping. The interior of the furnace and gages is kept dry by a tube of P_2O_5 in the bottom of the steel extension of the furnace tube.

The charges are contained in a small platinum crucible suspended by two platinum wires sealed into a glass cap, which is attached to a ground glass conical joint at the top of the tube above the furnace. The two wires of the platinum-platinrhodium thermoelement are also sealed through this glass cap, and the four wires are insulated from one another by transparent fused silica or Marquardt porcelain capillaries. The two suspension-wires may also be used as the leads for the determination of melting points, et cetera, by the quenching method.

There are three pressure gages: (1) a McLeod vacuum gage of 500 cc. capacity from Leybold (shown at M_1), (2) a similar gage of 50 cc. capacity made in this laboratory (M_2), (3) a mercury manometer read by means of parallel knife edges and a vernier, and reading to 0.01 mm. The latter is the manometer used in previous work on the nitrogen thermometer.[4] It has an excellent scale, calibrated throughout its length to 0.01 mm. by the Normal-Aichungs-Kommission in Charlottenburg. We removed the fixed level point used with the gas thermometer,

[4] Am. J. Sci. (4) **26**: 415. 1908. Carnegie Inst. Washington, Publ. No. 157, p. 19.

connected this arm across to the vacuum apparatus by a wide glass tube, and evacuated and sealed the open arm, thus making a closed U-tube manometer of the apparatus. The three gages, compared against one another at various pressures within their ranges, agreed within the error of their readings. We have in this combination of gages a range of pressure measurement from 0.000 001 mm. mercury up to about 2.5 atmospheres.

The furnace jacket is an inverted iron pot, closed at the bottom by a disk of Alberene stone through which pass (1) the two conductors in parallel which carry the current to the lower end of the platinrhodium tube, together with the tubes for the cooling water, and (2) the steel extension of the platinrhodium tube. The latter is surrounded by a water-jacketed steel tube and cap. A little mercury is placed in the bottom of the steel tube to insure good thermal connection with the furnace tube, so that the lower end of the latter will always be kept cold. The joint between the stone base and the flange of the jacket is made tight by means of a plastic cement made by Mr. J. Jost of the instrument shop of this Laboratory.

The jacket is evacuated independently of the inside vacuum by means of a May-Nelson pump. There is no connection between the inside high vacuum and the outside "ordinary" vacuum. No insulation or refractory material is used excepting a magnesia tube surrounding the platinrhodium tube. The outside vacuum removes any danger of collapsing the hot furnace tube at high temperatures, and also provides an efficient heat insulation. The furnace jacket is cooled by a coil of lead pipe on the outside carrying cold water. An observation window permits optical temperature measurements to be made from without as a check on the thermoelectric measurements within the tube.

The magnesia tube does not greatly affect the loss of heat from the furnace tube at the lower temperatures, where the loss by radiation is not great, but does have a noticeable effect on the efficiency at higher temperatures. For instance, 386 amperes raised the temperature to 790° without the tube, and to 809° with the tube in place. 510 amperes, however, which

produced only 1100° without the tube, gave 1308° when the tube was in place.

The uniformity of temperature was not tested by direct measurement, as a complicated arrangement of apparatus would have been necessary to permit of moving the thermo-element up and down in the completely sealed furnace. An equally sensitive test was made, however, by taking a series of measurements of the oxygen pressures produced by 0.5 gram charges of Merck's ferric oxide, heated under similar conditions but at various levels in the furnace. In our preliminary measurements of dissociation pressures the thermo-element junction was always placed 3 to 5 mm. above the top of the charge of oxide, so that the change in weight of the charge could be determined without uncertainty due to oxide adhering to the wires. It is obvious that near the top of the furnace the thermo-element, under these conditions, will be colder than the bottom of the charge, whereas near the bottom of the furnace the reverse will be true. Hence if the temperature of the thermo-element is set to the same value in both positions, the temperature of the charge, and therefore the pressure obtained, will be greater near the top than near the bottom of the furnace. If two or more pressures obtained near the middle of the furnace agree within the range of reproducibility of these pressures, proof is afforded that there is a space of uniform temperature equal to the distance between the highest position of the thermo-element and the lowest position of the bottom of the charge. Measurements can therefore be made on charges set in this part of the furnace with the assurance that the temperature of the charge is uniform and is represented accurately by the temperature of the thermo-element. This condition is further assured by packing deep charges into the crucible with a polished steel plunger which shapes the surface with a central well, so that the thermo-element can be placed actually within the charge without coming into contact with it.

The result of the uniformity tests is shown in Table I. The distance from the top of the furnace tube to the top of the crucible in millimeters is given in the third column, and the

pressure in millimeters of mercury in the fourth column. The degree of reproducibility of the pressures is shown by the second, third, fourth, and fifth measurements. The pressures at depths of 85, 92, and 95 mm. are practically constant. Since the depth of the crucible is 18 mm. there seems therefore to be a range of about 25–30 mm. in which the temperature is uniform within one degree, judging from the variation of pressure, which is of the order of magnitude of 0.01 mm. per degree under the conditions of the tests. For subsequent measurements the crucible was always placed in the middle of this zone, and the thermoelement brought near the center of gravity of the charge as explained above. The charges varied in depth from 5 to 10 mm.

TABLE I

Pressures obtained from Merck's Fe_2O_3 at 1100° at various levels in furnace

NO.	WEIGHT OXIDE	DISTANCE FROM TOP	PRESSURE
	mg.	mm.	mm.
1345	493.3	65	0.610
1347	502.9	75	0.330
1349	504.0	75	0.305
1351	502.9	75	0.320
1355	503.8	75	0.315
1358	501.8	85	0.215
1362	501.6	92	0.210
1360	507.1	95	0.195
1361	499.6	107	0.120

Glass stopcocks are the most troublesome part of a vacuum apparatus. We have found Gundelach's large right-angle stopcocks (Schiff's form) satisfactory for the present work. A stiff rubber-paraffine-vaseline stopcock grease must be used, however, to prevent the atmospheric pressure on the large surface from causing the cock to stick fast. The grease should be renewed occasionally, also, as it becomes gummy after use for a long time in a vacuum.

As Professor Morley has well said, a stopcock is usually nothing more than a located leak. It is necessary, then, to shut off the located leaks in the connections to pumps and oxygen supply by a mercury cutoff, shown at *C* in figure 1. Its construction

is evident from the drawing. This cutoff, like the gages, is operated by a plunger instead of a movable reservoir. The glass traps on either side prevent mercury from being shot into the furnace or the pumps by any accidental rush of gas.

With the mercury cutoff closed and the joint of the crucible suspension sealed with kollolith the apparatus is absolutely free from leaks. It has stood 27 days without showing a pressure greater than 0.0052 mm. of mercury. This pressure seems to have been produced by the slow evolution of gas from the large surface of glass exposed. This matter will be discussed more in detail in a later paper on the iron oxides.

The plunger-lift for the large McLeod gage, M_1, consists of a steel plunger in a smooth wrought-iron pipe, as the necessary dimensions are too large to permit of the use of glass. The dimensions need to be carefully proportioned, since the displacement of mercury by the plunger must be equal to the volume of the gage plus the volume of mercury in the annular space between plunger and cylinder when the gage is at its highest reading. The greater the clearance between plunger and cylinder, therefore, the greater must be the diameter of both. Ours consists of a plunger 50.5 mm. in diameter and 100 cm. long in a cylinder 53 mm. inside diameter and 102 cm. long. The steel plunger is just floating in the mercury when the gage is nearly filled, so that the mercury columns can be set accurately by a slight pressure on the plunger. The use of a plunger-lift of this kind does away with the raising and lowering of an awkward mercury reservoir, with its accompanying rubber tubing, leaks, and sulfur contamination of the mercury.

Oxygen is admitted by way of one or both of the calibrated bulbs at the right of the apparatus. We have made no provision for exact measurement of the amount of oxygen to be admitted, as it can be just as exactly measured by its pressure after admission to the apparatus. It is possible to get any desired amount of oxygen by expanding slowly from either the small or large bulb. These bulbs also serve, together with the space between the mercury cutoff and the pump stopcock, for the withdrawal of known amounts of oxygen from the apparatus.

The oxygen is stored over mercury in the glass gas-holder at the right.

To hold the temperature at 1450°, the furnace requires 580 amperes at about 1.8 volts. Its power consumption is therefore no greater than that of an ordinary wire-wound furnace, when the loss of heat in regulating-rheostats in connection with the latter is taken into account.

The current is supplied to the furnace from the secondary of a small 25 : 1 transformer. The primary of the transformer is supplied by a motor generator of 60 cycles and a voltage range from 0 to about 300 volts. The generator voltage is regulated by means of its field current, which is supplied by a 110 volt storage battery and passes through rheostats alongside the potentiometer. By regulation of the field current the furnace current can be regulated without any waste of electrical energy, and if the voltage applied to the motor of the motor-generator is reasonably constant, the temperature can be held constant without difficulty to one degree at 1500°. This degree of constancy is very often necessary for accurate measurements of the dissociation pressures of iron oxides, as these pressures change quite rapidly with changes of temperature.

BOTANY.—*Spring flowers in the fall.* J. B. NORTON, Bureau of Plant Industry.

To the ordinary observer of living things in their natural surroundings the various evidences of evolution have appealed in a more or less remote way as something that happened in the distant past. The modern experimental methods of hybridization and of study of mutating strains do not appeal with the necessary force to make us realize that evolution is potent now, as it was in the Carboniferous age. While these researches are interesting as showing means of preserving new characters once they originate, the average layman wants to see the actual appearance of a new character. The origin of some characters and their progressive development by gradual accumulation to a point at which the new element is of value to the organism

has always been more or less of a stumbling block to many students.

At the present season the varying blooming time of related species always has a direct interest from its evolutionary meaning. As an example, take our native and cultivated maples and magnolias. Some species bloom early in the spring before the leaves appear, while others wait until the foliage is developed and then bloom well on into summer. From our observations on other groups of plants or on the individuals in one species, this change does not seem hard to account for. In another case, however, the blooming period offers more serious difficulty. The common witch-hazel in this region blooms late in the fall, and yet shows by its behavior that it is a typical spring flowering tree, its fruit developing normally the next season. It seems as though this change must have happened all at once by a big mutation because the winter months would so seriously affect the young flowers and developing fruit that the evolution by slow change would not be able to take place.

Fig. 1. Flower buds of *Cornus Mas*, March, 1912, showing fruits of the previous fall. In the lower branch the bud scales have been removed. (× 1½)

Many other spring flowers have been known to bloom in the fall; but most of these cases are caused by a moist period following the summer drought, this alternation of drought and moisture serving the same purpose as that of cold and warmth. It is an interesting thing that this fall or winter blooming is associated with many of our weeds and ornamental plants introduced from

the Old World. Among them are some that are unusually interesting in that they perhaps throw some light on the problem of the origin of fall blooming in witch-hazel. On the Agricultural Grounds in Washington there is a specimen of *Cornus Mas* with a peculiar blooming habit. Every fall this tree blooms more or less abundantly and in many cases sets good fruit. An interesting feature is that not all the buds in an umbel covered by the same set of bud scales will necessarily develop into fall flowers. Many umbels hold some of the buds until spring, so that we have fall fruit and spring flowers existing in the same umbel (fig. 1). Apparently the tree is in a satisfactory transsition condition between spring and fall blooming from which the development of a fall blooming form could be easily accomplished by gradual changes in future generations. This perhaps sheds some light on the development of the fall flowering of witch-hazel without the necessity of a sudden mutation or without the necessity of moving its blooming period gradually through the winter months.

BOTANY.—*Tribroma, a new genus of tropical trees related to Theobroma.* O. F. Cook, Bureau of Plant Industry.

In connection with a study of the branching habits of *Theobroma cacao*, attention has been given to a related tree known in Guatemala as patashte, which affords a still more striking example of the phenomenon of dimorphism of branches.[1] The patashte tree has been placed with the cacao hitherto as another species of Theobroma, under the name *Theobroma bicolor*, but after a somewhat detailed comparison of the two trees in eastern Guatemala in 1907 it did not appear reasonable to assign them to the same genus. This opinion was strengthened during another visit to Guatemala in the spring of 1914, and it is now proposed to treat the patashte tree as the type of a new genus. The distinctive characters are stated in the following description:

[1] Cook, O. F., Dimorphic Branches of Tropical Plants: Cotton, Coffee, Cacao, the Central American Rubber Tree, and the Banana. U. S. Department of Agriculture, Bureau of Plant Industry, Bulletin 198. Pp. 39. 1911.

Tribroma Cook, gen. nov.

Slender, erect trees, with strong upright shoots, each ending in a whorled cluster of 3 lateral branches; leaves of upright shoots with long petioles and broadly ovate-cordate blades, palmately veined, naked above, clothed underneath with a very fine dense appressed stellate pubescence, like the surfaces of the branches and petioles; leaves of lateral branches broadly ovate-oblong, subsessile, the petioles very short, representing only the confluent pulvini; inflorescences with pseudodichotomous branching, with bracts at the articulations, forming a broad, loose panicle or dichasium, produced near the ends of the lateral branches, above the axillary buds of the young leaves, entirely confined to the new growth; flowers small, inconspicuous, dark-colored, dull reddish purple, the petals minute and the sepals only partly opened; sepals broadly triangular, inflexed; petals much shorter than the sepals, the basal hood with a single median rib, the limb rudimentary, represented by a minute oval, reflexed, nearly sessile appendage; staminodes robust, clavate, clothed above with short pubescence, naked below; ovary 5-angled, finely pubescent like the pedicels, sepals, petals and staminodes, but none of the pubescence glandular; fruits ellipsoid, with a very hard woody shell, the surface broken by deep irregular lacunae.

Type, **Tribroma bicolor** (*Theobroma bicolor* Humb. & Bonpl., Pl. Equinox. **1**: 94, *pls. 30a, 30b.*).

The generic name Tribroma alludes to the fact that the lateral branches are always produced in whorls of three. In Bernouilli's monograph of Theobroma the name Rhytidocarpus was used for the section that included *T. bicolor;* but to advance this name to generic rank seems inadvisable, in view of the previous applications of closely similar names, such as Rhytidocarpaea and Rhyticarpus, in other groups of plants.

The patashte tree is probably of South American origin, though the original habitat has not been determined. In Central America it is widely but rather sparingly cultivated by the Indians. The seeds are used for the same purpose as those of the cacao tree, though generally considered inferior in quality. The comparison of cacao and patashte was made at a locality called Cacao or Secacao, on the Trece Aguas Estate of Don Ricardo Fickert-Forst, in the Senahú District of the Department of Alta Verapaz, eastern Guatemala. Specimens collected at Cacao in May, 1914, are in the U. S. National Herbarium, the sheets bearing numbers 862202–5.

The contrasting characters of the genus Theobroma, as represented by its type species, *T. cacao*, may be stated as follows:

Low, shade-tolerant trees of tropical undergrowth, the lateral branches formed in terminal clusters of 5, rarely 4 or 6; leaves elliptic-obovate, narrowed toward the base, pinnately veined, naked on both surfaces, the petioles and young shoots hirsute with stiff erect bristles; leaves of lateral branches of the same form as those of the upright shoots, the petioles somewhat shorter, but the pulvini distinct at each end; inflorescences reduced to minute fleshy twigs, only the terminal joints distinct and these shorter than the pedicels of the flowers, produced from adventitious buds on old wood of the main trunk or the larger branches, long after the leaves; flowers larger than in Tribroma, the sepals and petals both conspicuous, light colored, widely expanded; sepals narrow, tapering and reflexed; petals longer than the sepals, strongly curved or folded in the bud, the basal hood with two strong parallel ribs, the limb longer than the hood and with a slender base folded down around the end of the hood; staminodes slender, naked and tapering above, laterally compressed below, with bands of long hairs on the lateral faces; ovary rounded, covered with glandular pubescence like the sepals and the pedicel; fruits obovate or fusiform, with a thick fleshy rind, longitudinally ridged and furrowed, the surface smooth or tuberculate.

A more detailed account of the differences between the two trees, with special reference to their habits of branching and their floral biology, illustrated by photographs, is being offered for publication in the Contributions from the United States National Herbarium.

PROCEEDINGS OF THE ACADEMY AND AFFILIATED SOCIETIES

THE BIOLOGICAL SOCIETY OF WASHINGTON

The 533d meeting of the Society was held at the Cosmos Club, Saturday, January 9, 1915, with President BARTSCH in the chair. About 40 members were present. WALDO SCHMITT of the U. S. National Museum was elected to active membership.

Under the heading Brief Notes and Exhibition of Specimens L. O. HOWARD made remarks on the meetings held at Philadelphia during convocation week. Dr. PILSBRY discussed certain aspects of the Hawaiian land shell problem, stating that early collecting was done in the valleys, but that recent work showed the chief home of species to be on the ridges. The distribution of forms occurred in groups and there were many instances of Mendelian inheritance between different forms carried out on a large natural scale.

The first paper on the regular program was by WM. PALMER: *An unknown fossil.* Mr. PALMER exhibited the specimen from the Calvert Cliffs of Chesapeake Bay and hoped members would express views as to its nature. His own view was that it might represent the lower jaw of an unknown turtle. From same locality other fossils were shown that had previously proved very difficult to identify. Mr. PALMER's communication was discussed by Professor HAY.

The second paper was by Professor HAY: *An albino terrapin.* The unique specimen was exhibited; it was hatched near Beaufort, N. C.; an attempt was made to raise it, but it lived only a few months. Professor HAY took occasion to show excellent lantern slides of certain interesting crustaceans especially of *Limnoria lignorum*, a wood boring Isopod, and of *Xylotria*, a wood boring mollusk. The communication was discussed by Messrs. BARTSCH, WILCOX, PALMER, SMITH, and HOPKINS, and by Miss RATHBUN.

The last communication was by M. W. LYON JR.: *Notes on the physiology of bats.* The speaker stated that little was known of the exact physiology of bats, but discussed the subject from the broad standpoint of their physiology of locomotion, of food, of adaptation, and of special senses. The need of careful experiments on use of, and modern histological work on structure of noseleaves was pointed out. The paper was discussed by Messrs. HOWARD, BISHOP, HUNTER, WM. PALMER and STILES; Mr. BISHOP giving an account of a bat roost near San Antonio, Texas, erected with the idea that bats would consume large numbers of malarial mosquitoes; Mr. HUNTER stating that an examination of stomach contents of bats showed that the food of *Nytinomus mexicanus* consisted of 95 per cent moths, the rest being carabid beetles, hymenopterous insects, and a few crane flies—the only Diptera found, no mosquitoes being observed.

On Tuesday, January 19, 1915, at 8.30 p.m., the Society held a joint meeting with the Washington Academy of Sciences in the Auditorium of the National Museum. Dr. JOHAN HJORT, Director of Fisheries of Norway, delivered an illustrated lecture on *Migrations and fluctuations of the marine animals of western Europe.* About 200 persons were present.

The 534th meeting of the Society was held at the Cosmos Club, Saturday, January 23, 1915, with President BARTSCH in the chair and 75 persons present. Mr. R. A. WARD was elected to active membership.

Under heading Brief Notes etc., Dr. JOHAN HJORT, Director of Fisheries of Norway, called attention to the large numbers of herring caught in Norwegian waters during the last few years, most of them belonging to what he termed the "1904 Class." Dr. HJORT attributed the great success of the "1904 Class" to the known lateness of season when it had been spawned and when the plankton was abundant. Early in spring the sea is practically barren of plankton and fish hatching at that time have little food.

The regular program consisted of an illustrated paper by Mrs. AGNES CHASE on *Developing instincts of a young squirrel.* Mrs. CHASE had made careful observations and notes on the bringing up of a young gray squirrel during the spring and summer of 1914. The animal was very young when received, needing to be fed on milk with a medicine dropper. Mrs. CHASE described its growth and its acquisition of squirrel-like habits and instincts. It was not brought up as a pet, but was given every freedom to develop its natural traits. At maturity it met with wild members of its own species, at first returned home, but finally remained away.

The rest of the evening was given over to an exhibition of lantern slides on biological subjects. W. W. COOKE showed views of bird life; H. M. SMITH, of the Japanese silk industry; WM. PALMER, of seals and birds of Pribilof Islands; PAUL BARTSCH, of local birds.

The 535th meeting of the Society was held at the Cosmos Club, Saturday, February 6, 1915, with Vice-President HOPKINS in the chair and 35 persons present.

Under heading Book Notices and Brief Notes Dr. RANSOM called attention to a new biological journal under the editorship of Professor Ward, of the University of Illinois, to be devoted to animal parasites. Mr. COOKE read a letter from Dr. B. W. Evermann, now of San Francisco, a former president of the Society.

The first paper of the regular program was by T. WAYLAND VAUGHAN: *Remarks on the rate of growth of stony corals.* Dr. VAUGHAN reviewed the work done by previous investigators and gave results of his own carefully conducted experiments at Tortugas. The paper was fully illustrated by lantern slides showing apparatus and methods employed in planting corals and results of one and of several years' growth of various corals.

The second paper was by J. N. ROSE: *Botanical explorations in South America.* Dr. ROSE spoke concerning a botanical exploration on the western coast of South America, which he made during the summer and fall of 1914. He stated that when he took up the study of the Cactaceae for the Carnegie Institution of Washington, it was with the understanding that it should embrace not only herbarium and greenhouse studies, but extensive field work in all the great cactus deserts of the two Americas. His going to the west coast was therefore simply part of a large scheme for botanical exploration. He further stated that plans had been made for similar field work in the deserts of the east side of South America during the coming summer. He gave detailed accounts of his work in the deserts of Peru, Bolivia, and Chile, and the peculiar Cacti which he found, described particularly the climatic conditions in those countries, and told of the remarkable crescent-shaped sand dunes of southern Peru. On this trip Dr. ROSE collected more than a thousand numbers, obtaining not only herbarium and formalin specimens, but also living material. His collection of living plants, which was very large, has been sent to the New York Botanical Garden. Dr. ROSE's communication was illustrated by maps of the regions traversed, by apparatus used in collecting specimens, and by preserved specimens. The paper was discussed by Messrs. HITCHCOCK, VAUGHAN, GOLDMAN and TOWNSEND.

The 536th meeting of the Society was held at the Cosmos Club, Saturday, February 20, 1915, at 8 p.m., with President BARTSCH in the chair and 65 persons present.

Dr. CHARLES MONROE MANSFIELD, of the Bureau of Animal Industry, was elected to active membership.

Under the heading of Brief Notes, Gen. T. A. WILCOX made observations and inquiries concerning the color of the eyes of certain turtles. His remarks were discussed by W. P. HAY. Dr. L. O. HOWARD described the successful campaign carried on against mosquitoes in New Jersey.

Under the heading Exhibition of Specimens, WM. PALMER exhibited the tip of the tongue of a sulphurbottom whale and considered the probable utility of its peculiar shape. Messrs. BARTSCH, HAY, and LYON took part in the discussion.

The regular program consisted of an illustrated lecture by H. C OBERHOLSER entitled: *A naturalist in Nevada.* Mr. OBERHOLSER gave an account of a biological survey of parts of Nevada made by himself and others some years ago, and described the geologic, geographic, and climatic characters of the route traversed by his party. He mentioned in particular the plants, mammals, birds, and reptiles observed and collected by the expedition, and pointed out how they were influenced in kind and numbers by the unusual geographic and climatic conditions found in Nevada. He showed many excellent views of the country and of the animals and plants encountered.

Mr. OBERHOLSER's paper was discussed by Messrs. HAY, BARTSCH, BAILEY, LYON, GOLDMAN, WETMORE, and WM. PALMER.

M. W. LYON, JR., *Recording Secretary.*

XI